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ARE WE RUNNING OUT? A PERSPECTIVE ON RESOURCE SCARCITY

A STUDY

PREPARED AT THE REQUEST OF

JOHN D. DINGELL, *Chairman*

SUBCOMMITTEE ON ENERGY AND POWER

COMMITTEE ON
INTERSTATE AND FOREIGN COMMERCE
UNITED STATES HOUSE OF REPRESENTATIVES

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LETTER OF TRANSMITTAL

CONGRESS OF THE UNITED STATES,
HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY AND POWER OF THE
COMMITTEE ON INTERSTATE AND FOREIGN COMMERCE,
Washington, D.C., July 12, 1978.

Hon. HARLEY O. STAGGERS,
Chairman, Committee on Interstate and Foreign Commerce, House of Representatives, Rayburn House Office Building, Washington, D.C.

DEAR MR. CHAIRMAN: Attached is a study performed by the Congressional Research Service for the Subcommittee on Energy and Power entitled: "Are We Running Out? A Commentary on Resource Scarcity." I believe that it would be useful if this study were to be published as a committee print.

The study, done by Mr. Alvin Kaufman, senior specialist in mineral and regulatory economics, reviews the concepts of resources and scarcity, and looks to both economic and institutional influences upon the stock of usable mineral and energy reserves. Divergent perceptions of the resource scarcity problem are characterized as a static or "storehouse" view on the one hand, and the "cost-price" view on the other. This CRS study attempts to reconcile these two views, and discusses the plausibility of each view over short-, medium-, or long-term time horizons. The concepts developed in the study are then applied to a particular example: Petroleum.

I believe all Members of the House will find the study to be of interest.

Sincerely.

JOHN D. DINGELL, *Chairman.*

Attachment.

LETTER OF SUBMITTAL

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CONGRESSIONAL RESEARCH SERVICE,
Washington, D.C., June 16, 1978.

Hon. JOHN D. DINGELL,
Chairman, Subcommittee on Energy and Power, Committee on Interstate and Foreign Commerce, U.S. House of Representatives, Washington, D.C.

DEAR JOHN: In your letter of March 17, 1978, you asked that we prepare a general analysis of resource scarcity for the use of the subcommittee.

Such a report is attached. This paper reviews the various scarcity concepts, applies scarcity theory to the M. King Hubbert theory on petroleum supply, and presents an analysis of the Lovins "hard" and "soft" paths.

The report was prepared by Alvin Kaufman, senior specialist in mineral and regulatory economics.

Sincerely yours,

GILBERT GUDE,
Director, Congressional Research Service.

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ARE WE RUNNING OUT? A PERSPECTIVE ON RESOURCE SCARCITY

SUMMARY

The concept of resource scarcity is almost as old as man. One of the most notable of the early forecasts was the Malthusian prediction of widespread famine. In more recent times this forecast has been renewed and compounded by forecasts of resource constraints, particularly in energy.

For our purposes we will view the movement of resources into the reserve category, and vice versa, as a process rather than a stock. The factors affecting this movement break down to internal, external, and institutional. The latter group is becoming more and more important as a stimulant or as the brake on the bus.

A review of the economic theory of resource scarcity indicates that it will not occur over the long term because of the ability of the economy to adjust and the consequent tradeoffs that result.

Petroleum can be viewed as a case in point. In this instance, M. King Hubbert has postulated a world peak in the 1990's at 37 billion barrels (B) assuming past trends continue. If demand stabilized at the current 20 B level, the peak would occur in 2035. Current estimates, taking account of higher prices, indicate demand will fall between the two curves.

We can conclude that while no one can predict with certainty the status of undiscovered oil, it appears relatively positive that the peak is at least 35 to 40 years off for the world, and probably longer, assuming demand growth somewhere between the two Hubbert curves. If this is correct, there is enough time for our energy situation to clarify, for market forces to work out new directions, and for the energy situation generally to settle down. The essential question then becomes, At what cost?

The imponderable in this situation is the willingness of those who control the bulk of the world's current oil reserves to permit the rest of us to use that oil at a reasonable social, political, and economic price. If political and other factors interfere the shortages created are artificial, although still quite real to those suffering. The answer to an artificial problem deliberately created by others is not necessarily the same as the answer required to solve true resource scarcity.

In any case, while the United States is not running out of oil, we will not be able to produce enough domestically to meet the bulk of our needs without turning to other sources such as additional imports or to oil shale, coal, etc. There is considerable controversy over this latter course.

Lovins outlines the social costs inherent in this "hard path" and suggests a "soft path", both of which he holds to be mutually exclusive. This is based on an estimate that on the hard path 75 percent of investment would have to be devoted to the energy industry. This

would mean that there would be virtually no growth in any other sector of the economy and, therefore, little need for all that extra energy. The soft thesis seems to be saying that potential resource scarcity cannot be dealt with in the usual manner without imposing substantial costs on society with little benefits. The difficulty is that the proposed solution may impose the very costs one seeks to avoid. Both paths carry with them great economic, political, and social uncertainty. In such a case it is often best to go down the middle, correcting course as necessary.

In presenting the above, we suspect we may have violated one of the canons of the economics profession. Since the time of Malthus, economics has been known as the dismal science, but our view of resource scarcity tends to be rather optimistic. This results from our belief that resources, like old soldiers, do not die on a global basis, these just fade away, only to be replaced by other resources.

Introduction

In the late 18th and early 19th centuries, an ordained British minister turned economist and produced one of the most famous predictions of resource scarcity. It was the theory of the Reverend Malthus that population growth would outstrip the expansion of food supplies thus resulting in widespread famine. His proposed remedy was prudence and self-restraint. The Reverend Malthus' predictions did not come true in the Western World because of the very rapid growth in industrial and agricultural productivity coupled with a declining birth rate.

The Malthusian thesis, however, has been advanced from time to time in regard to other areas and various other vital materials. In the 1920's and early 1930's, as the United States began its transition from a net exporter to a net importer of raw materials, much was heard about "running out." This was subsequently followed by the Paley Commission Report of the post-World War II era that talked, not about shortages, but about higher prices. Today, we seem to have come full circle. Once again there are discussions of shortages and "reaching the bottom of the barrel" for various mineral commodities. This is particularly true for energy materials. Yet, the world is different today than it was earlier in this century. These differences may make the predictions of doom appear closer to the truth. In any case, the question of the accuracy of these forecasts is not frivolous. On the answer hangs billions of dollars in research expenditures, still greater capital commitments, the policy direction in which we should be going, and our very standard of living and way of life.

Thus, a careful examination of the claims and counterclaims is called for. To this end, we present below a general framework for such an examination, together with its application to several examples. In the first instance, we will look at the concept of petroleum scarcity with emphasis on the Hubbert thesis. In the second case, we will examine the hard-soft-path concept.

RESOURCES, RESERVES, AND SCARCITY

Before discussing resources scarcity, we need to understand the context within which we intend to use the terms, and the general mechanics involved in resource development.

At first blush, it would appear that the terms are self-explanatory. Yet, part of the confusion that surrounds the subject results from the use of the words in a different context by different people.[1] For our purposes, we are only going to deal with three basic terms: Resource base, resources, and reserves.[2]

---

[1] For a detailed discussion of the various definitions and classification systems see: Brooks, David B.; "Mineral Supply as a Stock," a chapter in the "Economics of the Mineral Industry," 3d edition, W. A. Vogely, editor, AIME, 1976, 125-207 pages.

[2] Based on Netschert, B. B. "The Future Supply of Oil and Gas" Johns Hopkins Press for Resources for the Future, Baltimore, 1958, 134 pages.

The latter term we will define as material producible under current technologic and economic conditions. Reserves are the most precise category, although even here there is a great deal of estimation. Resources we will define as everything else. The resource classification can be subdivided into an almost infinite number of categories depending on various criteria. A common subclassification is to break resources into two major segments; submarginal and latent.

Submarginal resources are defined as those exploitable with relatively minor changes in economic and technologic conditions. Some authors define this category as material producible at a cost up to 1.5 times the current level, in real terms.

Latent resources require a major breakthrough in technology and in economic conditions. The definition of "major" is left to individual discretion, because of an inability to be anything but arbitrary. As a consequence, we will consider resources as a single class without further subdivision.

Resources and reserves together make up the resource base. The latter is all of a given material in the earth's crust. In other words, if we are considering petroleum in the world, the resource base would be all of the petroleum in the earth's crust regardless of the present or future feasibility of exploitation; reserves would be the sum of those petroleum deposits that can be produced under current economic and technologic conditions; petroleum resources would be the difference between the resource base and reserves.

The resource concept

In the discussion that follows we are going to concern ourselves primarily with resources and the way in which these move into, or out of, the reserve category. There are, however, a variety of ways to view a resource. It may be useful to explore these first, and settle on a concept for our use.

The majority of writers on the subject view a resource as a highly fluid thing; something that ebbs and flows with the changes in the human condition. For example, Ciriacy-Wantrup stated that a resource is a highly relative concept that will change with the user, his objective, the state of technology, and existing social institutions. At first he considered resources from the exhaustible and inexhaustible viewpoint, but subsequently decided that these terms differ only in degree. As such, the words denote time patterns of revenue and costs influenced by the cumulative use and chemical variation of the resource. Long before a given reserve is exhausted, or even appreciably diminished, it may shift into the resource category because the cost of production has risen to the point where it exceeds available revenue. On the other hand, a reserve may be virtually inexhaustible in the sense that utilization can continue indefinitely, even though it is limited in physical quantity, simply because the cost remains low in relation to revenue at all times. Changes in revenue and cost will occur as a result of changes in technology both in and out of a given industry and because of the accumulation of scrap and durable products which affect demand for the resource and, therefore, its price. The revenue/cost picture is also affected by changes in the quantity and quality of the resource. Ciriacy-Wantrup grouped all resources into stock or flow classifications. Stock resources were those whose physical quantity, for all practical purposes, has a finite limit and does not increase significantly with time. For example, the formation of coal may continue through time from the geologists' view point but for all practical purposes there is only a given quantity in the ground. As a result, each ton produced reduces the stock. Technological improvement in mining or preparation with consequent cost reduction, however, may maintain the reserve at a constant level so as to make the resource virtually inexhaustible.

Flow resources, on the other hand, are usually inexhaustible because there is a constant influx of resource. As a consequence, the present use does not diminish the future flow. These flow resources will vary quantitatively over time. There is no set stock of material, but rather a variable flow, which even with use may increase or decrease the size of the resource at any given time. Examples of these are animals or plants. Ciriacy-Wantrup would consider all mineral commodities to be in the stock classification.[3] This, however, would be disputed by Brooks.[4] He would take the view that most mineral byproducts should also be classified as a flow resource, in that the resource quantity of these is variable and their availability at any given time is governed by the output of some other material.

A somewhat different view from that of Ciriacy-Wantrup was taken by Scott.[5] He emphasized that the distinction between natural and artificial capital was irrelevant in terms of economic theory as was the distinction between stock and flow resources. Technology limits the applicability of the concept of a permanently fixed resource stock. The same principles of investment and decisionmaking apply both to stock and flow resources. Mineral resources of whatever kind must be regarded as a specific form of capital. Therefore decisions to invest or not to invest, to explore or exploit, must be made on the same basis as decisions about any other potentially productive investment.

The most useful concept, however, in terms of evaluating resource scarcity may be that propounded some years ago by Zimmerman.[6] He felt that minerals should not be considered as a finite resource. A mineral resource was infinite in the sense that man created reserves from resources as he needed material, through his ingenuity. In short, nature provided the material, which does have a finite limit; civilization or cultural attainment provided the need or demand; and man provided the method for utilizing it. Resources thus are propelled into the reserve category, or vice versa, through the interaction of natural, cultural, and human factors. In some instances, this interaction may result in the lessening of the importance of one kind of material while creating another. For example, the invention of a method for extracting nitrates from the air virtually destroyed the Chilean mineral nitrate industry while creating an almost unlimited reserve of this material throughout the world.

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[3] Ciriacy-Wantrup, S.V.; "Resource Conservation: Economics and Policies", University of California Press, Berkeley, 1952, 295 pp.

[4] Brooks, David B.; "Goals and Standards of Performance for the Conservation of Minerals: A Comment" Natural Resources Journal, May 1965, volume 5, 49–53 pp.

[5] Scott, Anthony; "Natural Resources: The Economics of Conservation." University of Toronto Press, Toronto, Canada, 1955, 184 pp.

[6] Zimmerman, Erich W., "Introduction to World Resources", edited by Henry L. Hunker, Harper & Row, New York, 1964, 220 pp.

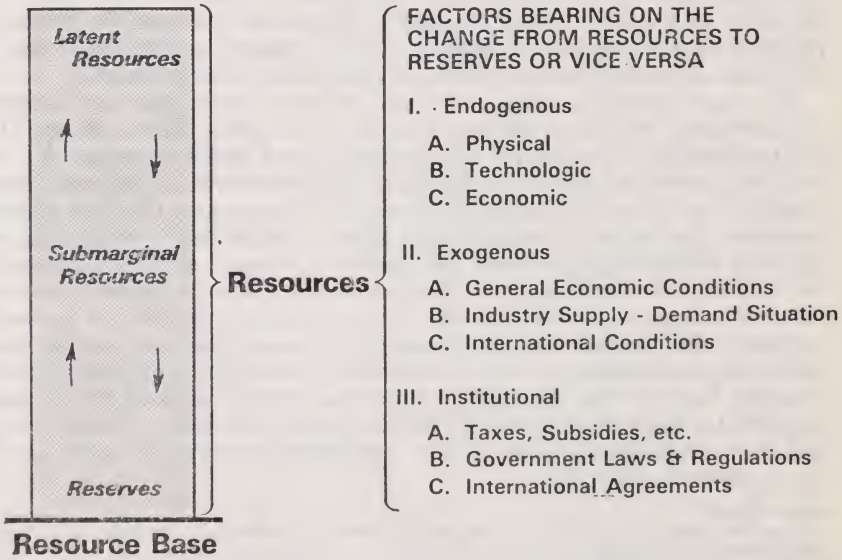
From the foregoing, it would appear that while the mineral resource base has a finite limit, the fluctuation between resources and reserves is conditioned by a host of factors. Vogely has noted that we are dealing with a process and not a stock of material. Resources will move up or down in classification in response to human wants and needs as expressed through the social and economic systems. The manner in which this process operates then becomes the critical element.[7]

Resources to reserves

We can now turn to an examination of the process. Essentially this can be expressed as "today resource is tomorrow's reserve, and vice vice versa". The latter indicates the fact that mines and oilfields do become depleted or reach a point where costs make further operation uneconomic only to be replaced by other producing properties or by substitute commodities.

On the other hand, submarginal resources move into the reserve category in response to the influence of three groups of factors. These tend to be highly interwoven so that it is difficult to determine the relationship between the groups let alone the specific factors.

Figure 1. Resources & Reserves, A Schematic Representation


Latent Resources
Submarginal Resources
Reserves
Resources
Resource Base
FACTORS BEARING ON THE CHANGE FROM RESOURCES TO RESERVES OR VICE VERSA
I. Endogenous
A. Physical
B. Technologic
C. Economic
II. Exogenous
A. General Economic Conditions
B. Industry Supply - Demand Situation
C. International Conditions
III. Institutional
A. Taxes, Subsidies, etc.
B. Government Laws & Regulations
C. International Agreements

In an earlier paper the author classified the factors as endogenous (internal), exogenous (external), and institutional.[8] The endogenous items are those internal to the deposit (fig. 1). That is, those physical, technologic, and economic factors that bear on the cost of mining, preparing and delivering the product to the marketplace. This would include not only transportation, but geographic circumstances that affect cost such as elevation, climate, geologic conditions, health hazards of mining, and the various inputs to the production process. The latter would comprise labor, water, energy, and so forth. These simply sum up the ability of a given mineral occurrence to compete on both economic and technical grounds. In short, the deposit must be competitive in regard to technical specification as well as cost of production.

---

[7] Vogely, W.A., "Oil and Gas Reserves and Resources Information Systems" Pennsylvania State University, September 1977, p. 11.

[8] Kaufman, A. "An Analytical Framework for Potential Ores," Engineering & Mining Journal, June 1967, pp. 214–216.

Despite the ability of the deposit to compete with other similar deposits, however, factors external to development may prevent its exploitation. These include current, as well as forseeable general economic conditions, and the supply-demand situation in the specific industry. That is, one will not undertake the research, exploration, and investment required to convert a resource into a reserve unless one feels confident of the future. The finding and research costs must be followed by development as well as plant and equipment expenditures, so that funds are tied up for the years from discovery to production. As a consequence, research and exploration undertaken during a period of prosperity may not begin to bear fruit until a period of economic decline. An investor must believe this will not occur, otherwise he will be reluctant to put his money down. In addition, there are impacts from changing social preferences and mores which can also delay exploitation.

Aside from the general economic situation, the specific supply-demand condition may be of greater importance. If the market isn't there, it will be difficult to spur development of additional deposits, or even to get people to look.

The most important group of factors, however, may be those we classify as institutional. These constitute governmental regulation, and may extend to health, safety, and environmental rules, taxes, tariffs, subsidies, aid to other countries, and even treaty arrangements. The latter may become of even greater importance as we attempt to negotiate with third world countries to "stabilize" prices, supply, and demand. In other words, if we steadily substitute the judgment of a small group of regulators for the collective judgment of the market in order to achieve various social goals. the actions of the Government will become overpowering, at least in terms of its impact on resource development.

In a larger sense, the institutional factors in Western industrial nations generally are an effort to internalize the external costs. That is, to make the private costs come closer to those experienced by society as a result of the production of this material.[9]

Resources scarcity

There is general agreement that resources become reserves and vice versa, and that the quantities of each will vary over time. There is also agreement on various factors that effect the transition from one category to another. The consensus falls apart, however, over the question of whether there is enough of a given material to meet our needs. This lack of agreement results from different views of the problem. The extremes range from what I call the "storehouse" view to the cost-price view; in between there is infinite variety (fig. 2).

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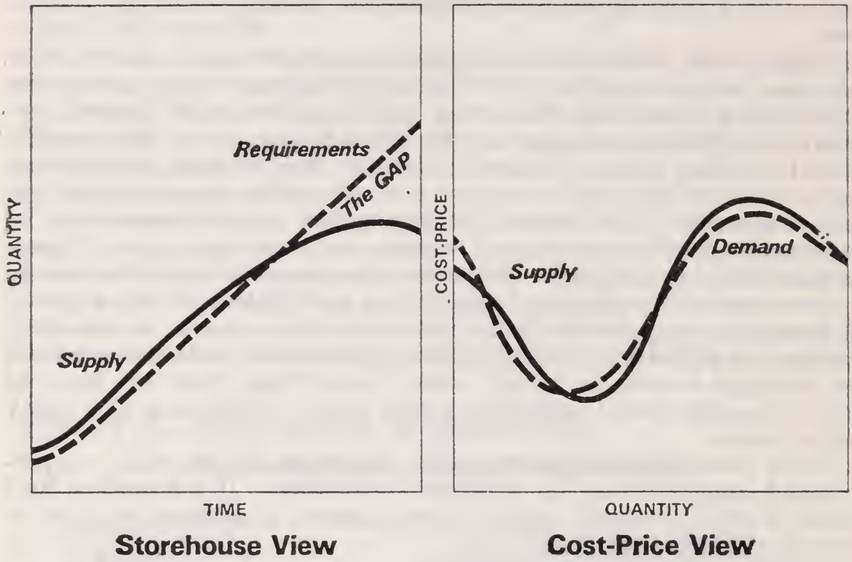
[9] For a more complete discussion of this issue see: Herfindahl, Orris C.. "What is Conservation?" in Three Studies in Mineral Economics, Resources For The Future, 1961, pp. 1-12; and Herfindahl, O. C. and A. V. Kneese, "Economics Theory of Natural Resources," Charles E. Merrill Publishing Co., Columbus, Ohio, 1974, 405 pp.

Figure 2. Two Views of Resource Scarcity



The "storehouse" view is generally held by geologists, mining engineers, and others in the mineral industry. It assumes that for any given material there are a limited number of deposits containing a sufficient concentration of the mineral to be useful to man. Once these have been exploited the store will be empty, but before we reach that point it will become more and more difficult to find suitable deposits. Such a view is often colored by the physical and geologic uncertainties encountered in the daily search for ore, and assumes that the technologic and economic circumstances of the past will be repeated in the future. There is also a tendency to develop, through extrapolation, a requirement figure for future demand which when compared with the limited supply usually results in dire warnings of catastrophe. The warnings may be right, but the method assumes a world of mechanical trends in which people march to the edge of disaster like lemmings.

On the other extreme are the cost-price types, who assume that as price goes up, consumption will drop. Mineral resources for all practical purposes are unlimited in terms of demand, and are in fact only defined by cost rather than by a physical limitation. Under this view mineral resources need not be considered finite in the sense of ultimate exhaustion. Advocates of the cost concept would view shortages as a short-term phenomenon and would insist that society can get what it wants by bringing marginal properties into production or through the development of substitutes as prices rise. In any case, costs would continue to decline through the introduction of new technology.

An empirical basis for this theory was laid by Barnett and Morse.[10] Their investigation showed that over the 1870–1957 period, the labor-capital cost per unit of mineral product declined by more than half, and dropped at a faster rate than all other goods and services in the economy. This infers that particular products may suffer cost increases from time to time, but substitutes and cost-reducing innovations, including new discoveries, will be introduced to alleviate the situation. Costs decline over the long run or the market for the product disappears, but resource extinction does not occur in the physical sense. Even if there were no cost-reducing innovations, the stock of a resource would not remain constant, but would tend toward depletion. That would lead to scarcity in the short run, followed by relative cost changes. The latter would induce an offsetting shift in society's use of the material or in the development of substitutes thus avoiding the physical extinction of the material. Barnett and Morse concluded that there is no natural resource scarcity in a real sense.

In recent years, the view that technology has acted as a renewing resource for raw materials has been challenged. In the past, technologic change has made it possible to extract materials from lower grade deposits while keeping costs at least constant, and in many cases resulting in a reduction. It is now felt by some that this era is at an end, and that a major constraint may be the ability of the environment to absorb waste.

In any case, one must keep in mind, that because of the heavy fixed costs inherent in mineral production, there is a certain inflexibility in the response of both supply and demand to price-cost changes. As indicated in figure 2, as costs decline, supply increases; as cost rises, supply continues to increase but at a slower rate until new sources enter the market and costs begin to decline once again.

Demand on the other hand, will increase as price drops and continue to increase, but at a slower rate, as price rises to a peak. It will then grow at a faster rate as price begins to decline again. Along the way there will be times of oversupply, times of shortages, and for brief periods even equilibrium.

These curves are an idealized version of a theory and, as such, do not necessarily fit any particular commodity. There are conditions under which supply and demand might decline in response to price-cost changes, etc.

In any case, it is obvious that the two views outlined above are not mutually exclusive, but rather somewhat complementary. To pursue this further we need to consider time. To this end we can outline three time periods: the short run, intermediate, and long run. The short run would be the period during which productive capacity could not be increased. The intermediate period is that time during which reserves cannot change but productive capacity can be changed to take full advantage of the existing level of reserves. The long run is the period in which everything is variable; new reserves or substitutes can be developed through exploration and research and new capacity can be created through investment. In considering the above, one must keep in mind that productive capacity includes the full production cycle beginning with mining of the raw material the various intermediate steps in production (smelting, refining, and forming) and the transportation network that binds all of these together. Limitations on capacity can be imposed by any of these stages of production.[11]

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[10] Barnett, H. J. and C. Morse, "Scarcity and Growth," John Hopkins Press for Resources For the Future, Inc., 1963, 288 pp.

In the short run, such limitations can result in shortages. That is, if demand for a given material were to expand beyond the levels expected, or if institutional factors were such as to discourage exploration and investment, sufficient capacity might not be in place. In such a case, shortages would occur, prices would rise if the Government permitted, demand would decline, and presumably the system would move back into balance. The converse, in terms of oversupply, could also occur.

In the intermediate period, shortages are also possible. A rather good example is U.S. natural gas. The Government, for various reasons, has held the price down below replacement cost. In large measure this resulted from public confusion between average and marginal cost. In any case, people stopped looking for gas while investment continued in pipelines, processing and distribution facilities to accommodate soaring demand. The latter rose because of the lower Btu cost compared with other fuels, the extraordinary convenience, and the ease in meeting all applicable air pollution rules. The result is an intermediate-term shortage in which productive capacity expanded to work available reserves until those reserves were unable to support the burgeoning demand. The result has been some increase in price coupled with regulations restricting demand growth. Had prices been permitted to rise to their market clearing level, a substantial economic surplus would have accrued to the producers as an incentive to find and produce more gas. It is over the disposition of this surplus that the current political battle regarding deregulation has been raging. Should it go to the consumer, the transporter, the producer, or all three? If to all, in what proportion to each?

Over the long term, however, where everything is variable, a "shortage" is not theoretically possible. Prices move up or down, productive capacity and reserve expansion grow or shrink, so that supply and demand are in balance over time. If there is a resource constraint, prices should rise to signal the impending shortage, substitutes enter the market, and eventually everything comes out even. In today's world, however, governments usually step in for reasons of social equity, but with the effect that prices give both the consumer and the producer the wrong signal. Government then tries to compensate by a welter of regulation in order to achieve the same result as higher prices. Therefore, while a long-term shortage is not possible, there may be a large number of short- or intermediate-term shortages.

In addition, over the long term a country may be forced to trade off resource availability against other economic inputs, such as economic growth, living standards, inflation, etc. For example, a recent CRS study indicated that if it were necessary to restrict energy use in the United States so that consumption was 18 percent below what it would be in 1990 assuming business as usual, and assuming the economy was sufficiently flexible to take up the slack through greater inputs, of capital, labor, and other materials, then GNP would be less than 1 percent below the base case, but total productivity would be 3 percent less. The latter indicates a greater tendency toward inflation.

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[11] Brooks, D. B. cited in footnote 1.

On the other hand, if the economy cannot adjust inputs, GNP would be 9 percent below the base, while capital and labor inputs would drop 8.5 and 8.8 percent respectively. Total productivity would be virtually constant. Thus prices would be stable, but economic growth would be sluggish.[12]

From the above we can postulate that resource scarcity over the long term will not occur because of the tradeoff with other things. For example, the tradeoff may involve an economic price such as slower economic growth or greater inflation, etc. The kind and severity of the tradeoff is dependent on the ability of the economy to substitute capital, labor, and other materials for the scarce item. In the past, the economy has shown itself remarkably resilient, and there is little reason to expect it to be less so in the future.

A CASE IN POINT—PETROLEUM

From the foregoing discussion, it is apparent that the "storehouse" and "cost-price" people are not telling us the same thing. The "storehouse" types are saying that all things remaining equal, we are going to run out. The "cost-price" types, on the other hand, are saying that all things do not remain equal, but in any case running out is not the problem. The problem is the costs that we will incur as we move to lower grade and substitute materials. When these two approaches are put together, it is apparent that there is a resource constraint, but that it may not be important over the long term. The question, in this instance, is our willingness to pay the potential social and economic price that may be exacted.

In recent years, there has been a great deal of conversation in regard to the ability of the world to provide itself with fossil energy, specifically petroleum, and the dire consequences of our inability to do so. As a result, this commodity readily lends itself to a case study of the scarcity theory.

Are we running out of oil?

Before attempting to assess the potential social and economic price of running out, it would be useful to determine if we are indeed on the verge of final depletion of our petroleum resources. Essentially, this is unanswerable. The question of final depletion revolves around the quantity of oil as yet undiscovered. The latter figure is, by definition, an unknown. Despite this obvious fact, the question is of considerable policy importance, and answers have been attempted by many people.

The Hubbert thesis.—In a recent publication, M. King Hubbert predicted an ultimate world oil production of 2,000 billion barrels, with 1,660 billion barrels remaining to be discovered (fig. 3).[13] If there is an orderly evolution of the industry, output would peak at 37 billion barrels per year in the mid-1990's, and decline from then on to zero by approximately 2075. On the other hand, if world production can be stabilized at the present rate of 20 billion barrels, the peak would not occur until the year 2035, declining to zero after 2100. The Hubbert estimates carry considerable weight because of his earlier ability to call at least the first peak in U.S. output. Therefore, it would be useful for us to review his thesis and some of the criticism.

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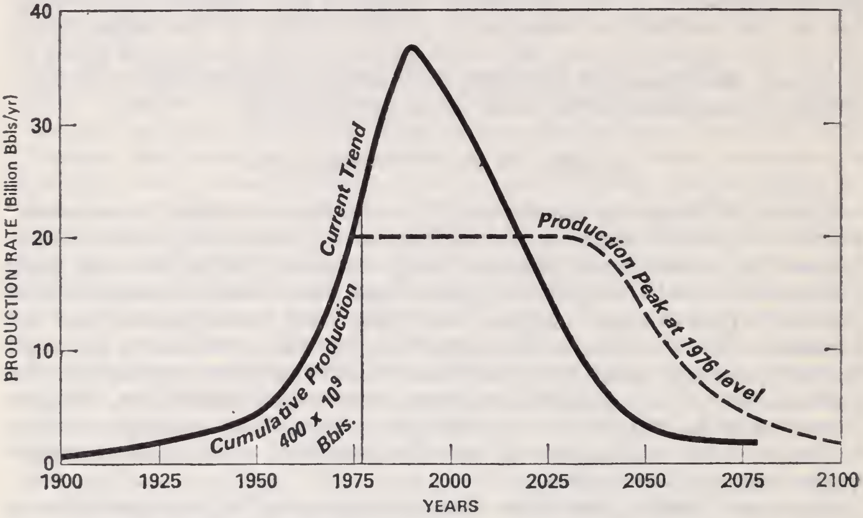
[12] Kaufman, Alvin and Barbara M. Daly, "Alternative Energy Conservation Strategies: An Economic Appraisal," CRS, for the Committee on Science and Technology, U.S. House of Representatives, committee print, June 1978, 182 pages.

[13] Hubbert, M. King, "World Oil and Natural Gas Reserves and Resources", chapter in "Project Interdependence: U.S. and World Energy Outlook Through 1990", U.S. Congress, Committee Print 95-33, Nov. 1977, p. 632-641.

Figure 3. World Oil Production Cycle By M.K. Hubbert[1]



Source: Project Interdependence: U.S. & World Energy Outlook Through 1990; Committee Print 95-33, p. 644

Hubbert outlined his method in detail in earlier papers on the United States.[14] In those treaties he noted that ultimate oil production is the key value; the larger that number, the longer the production curve. The latter was derived intuitively by most authors until 1956 when Hubbert unveiled his first "Hubbert pimple". This curve is derived through a trend analysis of several variables.

Hubbert determined that cumulative production (Qp) and proved reserves (Qr) equaled cumulative discoveries (Qd):

$$Qd = Qp + Qr.$$

If the Qd was then fitted to a logistics curve, the area under the curve is equal to ultimate oil production (Q). He also determined that the discovery curve precedes the production curve by a constant time interval, so that one can tell what production will do by what discoveries are doing. Through this kind of analysis, he found that the discovery curve for the Lower 48 States and the offshore areas peaked in 1957, and that the proved reserves curve peaked in 1961–62. Hubbert then determined that the lag between cumulative production and cumulative proved discoveries was 10.5 years. On this basis he concluded:

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[14] Hubbert, M.K. "U.S. Energy Resources, A Review As of 1972." Committee on Interior and Insular Affairs. U.S. Senate, committee print, 1964, serial No. 93-40 (92-75) and numerous earlier publications by the same author.

1. The discovery peak for the United States occurred in the second half of the 1950 decade;
2. The proved reserves peak would occur in 1962;
3. The production peak would occur in 1967–69; and
4. $Q = 170$ billion barrels.

The above conclusions, with the possible exception of No. 4, were astonishingly accurate. As a consequence, there has been a steady movement by knowledgeable people toward the Hubbert thesis, if not his method.

The Hubbert system, however, has some serious conceptual and methodological faults. These are discussed most cogently in a recent paper by Harris.[15] In that effort, the methodological difficulties are discussed in considerable detail and we will not repeat that material. Suffice it to say that Harris maintains the curve-fitting procedure used by Hubbert is inherently unstable and a poor application of statistics.

In terms of concept, however, we do need to explore the waters somewhat more deeply. The Hubbert model is based on two implicit assumptions. First, that past trends will continue into the future, and, second, that there are few large deposits left to find. In the latter case, his argument would be that statistics indicate that most of our oil reserves are in a very small percentage of the total number of deposits, and these giant fields, because of their prominence, are found first. In addition, there are few major provinces left to explore. Therefore, the incidence of future major discoveries is likely to be minor. It is true that typically most of the known reserves in a well-explored region occur in a few fields and are usually found first. What is true for a region, however, is not necessarily true on a global or continental basis. When we consider the world as a whole we are considering a composite of regions where exploration and discovery have different timing in each region. As we discussed earlier, there is a constant ebb and flow of resources into and out of reserves based on the interplay of various factors. Each time we move into a new area, such as the North Sea or Alaska, the probability of making a major find is greater than in the established producing regions. As a result, the Hubbert worldwide curve could be substantially changed as we move into new areas. Presumably he would argue, however, that this cannot occur, because we have located most of the giant fields.

Grossling, however, indicates that we have only just begun to look (figs. 4 and 5).[16] He estimates that the United States, Middle East, and the U.S.S.R. jointly possess about 28 percent of the world's prospective petroleum area, but account for 72 percent of the cumulative oil production plus proven reserves. Areas such as Latin America, Africa, the western Pacific and South-Southeast Asia contain 47 percent of the prospects but only account for 20 percent of the world cumulative oil production plus proved reserves. Further, 95 percent of the exploratory drilling has occurred in the developed countries, while only 5 percent has occurred in developing countries. The latter contain 50 percent of the world's prospective area. It should also be noted that the drilling outcome was more favorable in Africa and

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[15] Harris, D.P., "Conventional Crude Oil Resources of the U.S.: Recent Estimates, Methods for Estimation and Policy Considerations," Materials and Society, volume 1, Pergamon Press, 1977, Great Britain, p. 263–286.

[16] Grossling, Bernardo, F., "A Critical Survey of World Petroleum Opportunities," a chapter in Committee Print 95–33 referred to in footnote 12, pp. 645–658.

Latin America than in Western Europe and the United States. The Middle East, however, dominates in terms of giant fields discovered, with the rest of the underdeveloped countries ranking rather low. Grossling concludes that the potential of half of the world's prospective petroleum areas has been underestimated. The question of whether the people who have the oil are willing to sell it to us is a different matter not covered in this paper.

Figure 4. Prospective Petroleum Areas

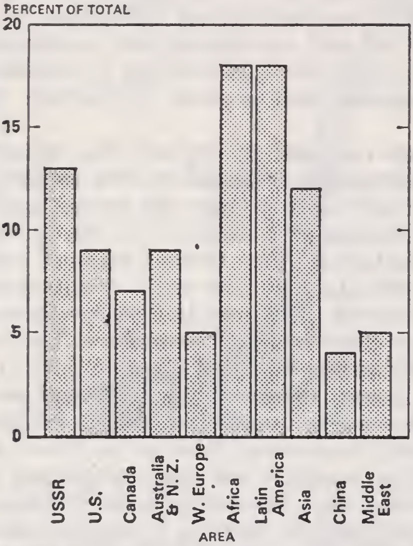
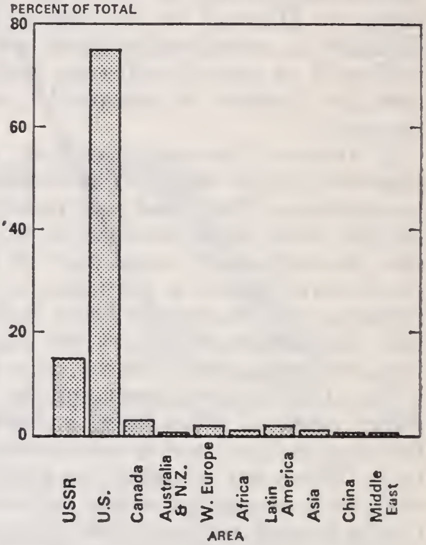


Figure 5. Cumulative Exploratory Wells Drilled by Area



Source: Grossling, B.F. "A Critical Survey of World Petroleum Opportunities" Committee Print 95-33

The Grossling theory of minimal exploration in what he considers as more promising areas is supported somewhat by the data in table 1. It is apparent that the bulk of the funds classified as exploration are being invested in established areas such as the United States, Canada, and Western Europe, with only 23 percent of the expenditures being made in other areas of the world. Approximately the same pattern is exhibited by the capitalized production investment, except that Africa, the Far East, and Canada received a substantially lower proportion while Western Europe and the Middle East received a substantially higher ratio.

This imbalance may not be so strange when one considers that in opposition to the Grossling thesis many other competent geologists maintain that geophysical surveys have eliminated large areas of his prospects as not having sufficient sediment thickness (1,000 meters) to generate temperatures adequate for the conversion of organic material into petroleum, or to produce sufficient pressure to assure migration to areas of accumulation. They would maintain the current surveys are adequate and drilling is not needed.

Further, some of his offshore areas appear to consist of terrestrial sediments which tend to be poor petroleum source rocks. If this is correct, areas such as the Argentine and East Asian Continental Shelves, Cook Inlet in Alaska, and the U.S. east coast may all turn out to be minor, rather than major, oil and gas provinces.

TABLE I.—PRODUCTION AND EXPLORATION EXPENDITURES FOR CRUDE OIL AND NATURAL GAS, 1976, BY MAJOR AREAS [1]

Area	Percent of total		
	Production [2]	Exploration [3]	Total [4]
Africa	4	7	4
Far East	5	8	5
Middle East	6	3	6
Western Europe	18	13	17
Western Hemisphere:			
Canada	6	10	7
United States	55	54	55
Venezuela	1	(5)	1
Other	5	5	5
Total free world (millions)	$23,860	$2,535	$26,395

[1] Adapted from Dobias, R. S. N. S. Anderson, and R. C. Sparling, "Capital Investments of the World Petroleum Industry—1976," Chase Manhattan Bank, December 1977, p. 12.
[2] Capital expenditures for finding and developing reserves.
[3] Geological—Geophysical expenses and lease rentals.
[4] Production and exploration.
[5] Less than 1 percent.

From the above we can conclude that there may be more oil out there than anticipated, but this is essentially an unanswerable question. The major failing of the Hubbert model in this regard, however, is the extrapolation of regional phenomena to the world. Considering differences in timing, exploration rates, etc., such extrapolation does not appear appropriate.

Of perhaps greater moment, however, is the model assumption that past trends will continue into the future. This tends to negate the shift in economic factors that has occurred since 1973. Prior to that date, it is possible that world prices did not reflect replacement costs, but since the embargo these must, at least, be at that level. As a consequence, it is highly likely that future world oil demand will grow at much lower rates than envisioned in the past. As Hubbert indicated in his alternative scenario, a stabilization of world production at the current level would move the peak out by 40 years. Most current demand estimates tend to fall between the two Hubbert production curves,[17] so that even if he is correct in his estimate of undiscovered oil, the peak would not occur until at least 2015, all other things being equal. The latter, however, is not the way things work, as discussed earlier. Higher prices resulting from resource depletion, if not distorted by institutional factors and radical inflation in costs, will dampen demand, provide an incentive to explore in less promising areas, make resources that would not be considered earlier into reserves, and make it economic to develop technology to enhance recovery from existing reservoirs. In addition, substitutes can be expected to enter the market. The impact of economics and technology will offset the consequences of natural resource depletion on a worldwide basis. Resources, like old soldiers, do not die on a global basis; they just fade away to be replaced by other things.

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[17] Lichtblau, John H., "World Oil Supply and Demand, 1950–76 and Forecast to 1990," a chapter in committee print referred to in footnote 12, pp. 675–689.

If the Hubbert estimate turns out to be optimistic, the events indicated above would occur at an earlier date. There would, however, be several years of economic dislocation while the economic and political systems attempted to sort things out. Shortages would occur from time to time, conservation would become the watchword, and OPEC would wield even more market power than currently. Eventually as new energy-efficient processes and sources became available, the transition would become less chaotic. The major impact of an earlier peaking of oil output would be a disorderly, painful, and perhaps dangerous transition to a new energy economy.

On the other hand, if the Hubbert estimate of undiscovered oil is pessimistic, as Grossling indicates, then as the new fields enter production, prices of petroleum and other energy materials will drop in real terms. This will stimulate demand; cause a weakening, if not collapse, of OPEC; result in a reduction of the conservation ethic; but probably not a return to the pre-1973 energy economy. The earlier days of plentiful, very low cost energy will probably not return even under this case because replacement costs will remain above earlier levels. In other words, production will be coming from higher cost area in any case—those that are more remote, in deeper or rougher ocean water, somewhat smaller deposits, etc.

In any case, we can conclude from the foregoing that while no one can predict with certainty the status of undiscovered oil, it appears relatively positive that the peak is at least 35 to 40 years off for the world, and probably longer, assuming demand growth somewhere between the Hubbert curves. This should be enough time for the situation to clarify, for market forces to work out new directions, and for the energy situation generally to settle down.

The U.S. situation.—It is difficult to estimate the petroleum future for the United States because institutional factors in the form of complex price controls, environmental regulation, and other items of this kind tend to distort the results.

As noted earlier, U.S. production reached a peak of 4.1 billion barrels (B) in 1970, declining to approximately 3.5 B per year in the 1975–76 period. Over this same time period, reserves also declined, except for 1971. In that year, reserves discovered in the Prudhoe Bay field in Alaska (10 B) were added to the national total resulting in a 32-percent jump from 29.6 B in 1970 to 39 B in 1971. Reserves as of January 1, 1978 are estimated at 35.5 B, compared with 37.3 B in 1977 (including gas liquids). This decline, however, was less than had occurred in the previous year because of a sharp rise in crude reserves added by new field discoveries from 68 million barrels (m) to 160 m, coupled to a rise in reserves added by extensions to existing fields from 62 m to 109 m. It is too early to tell whether this constitutes the beginning of a new trend.[18]

The reserve numbers published by industry, however, constitute a working inventory and as such may fall short of the actual reserves. In any case, there are three basic questions that require discussion in order to illuminate the future U.S. oil situation. These are: (1) Do we have oil left in the ground? (2) Can we find it fast enough?; and (3) What future production rates can be supported?

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[18] Oil and Gas Journal, "High Drilling Rate Slows Decline of U.S. Reserves," Apr. 17, 1978, pp. 53–57.

Undiscovered resources.—Estimates of undiscovered crude made between 1974 and 1976 by five groups show a range between 72 B by Hubbert and 118 B by Exxon with an average of 96 B.[19] The most recent Geological Survey estimates ranged between 46 B and 143 B with a median of 89 B. The high estimate represents resources having a 5-percent chance of proving out; the low has a 95-percent chance. The Survey data indicates the Alaska and Outer Continental Shelves (OCS) together comprise between one-third and one-half of our undiscovered resource. The lower estimate is at the 95-percent probability level and the higher figure is at the 5-percent level. The uncertainty inherent in the Alaskan-OCS data is indicated by the fact the "Lower 48" onshore high estimate is approximately double the low estimate, but the Alaska data is over 5 times higher and the OCS more than 3 times. This uncertainty is highlighted by the relative lack of drilling in those areas. Only 3 percent of the OCS has been drilled and a few hundred more holes in those areas would tell us more about our potential oil resources than exploration onshore. To the above figures would have to be added liquids extractable from coal, shale, etc. These nonconventional sources would undoubtedly move into the marketplace as prices rose to signal eventual resource exhaustion. In reality the resource would never become exhausted, but would price itself out of the market, to be replaced by substitutes such as oil shale, etc, at presumably higher prices than exist today, at least in the intermediate term. Higher prices should also encourage enhanced recovery of existing reservoirs.

In any case, considering the uncertainty inherent in the numbers, these should not be taken too literally. If we act on the assumption that we are going to "run out," the assumption could become a self-fulfilling prophecy. There will be a reluctance to provide incentives for oil production while providing such arrangements for other fuels. The result will be a skewing of the supply-demand curves away from oil, resulting in an empty oil barrel. In a more perfect world the market will rectify the situation. In our world, institutional factors and attitudes can make a substantial difference. When faced with great uncertainty, prudent men usually go incrementally down the middle rather than commit to one side or the other.

In this connection, we should note that the oil companies are diversifying into fields other than energy (retailing, copper, etc.). Such a diversion of oil cash flow from traditional investments could indicate that the companies believe the end of the oil rainbow is in sight and are preparing for corporate survival. On the other hand, it could also indicate their feeling that greater profits can be earned outside the energy field with less Government regulation. We tend to believe the latter on the grounds that possible resource exhaustion would encourage additional investment in alternative energy sources rather than outside the industry altogether. The companies may, of course, feel they already have an adequate portfolio of nonoil energy investments, and be simply hedging their bets.

From the discussion above, it does seem that there is still oil to be found in the United States, particularly in frontier areas such as Alaska and the OCS.

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[19] Much of the data used in the discussion of the U.S. situation is derived from the following sources:
(a) Riva, J. P. Jr., "Present and Future Domestic Supply of Oil and Natural Gas Liquids" chapter in U.S. Energy Demand & Supply 1976–85, Committee Print 95–43, March 1978, pp. 35–43.
(b) Energy Information Administration, Annual Report to Congress, vol. II, 1977.
(c) Kaufman, A. " esources, Reserves, and Project Independence," Henry Krumb lecture, AIME, 1975.

Oil discovery.—New sources of oil must be found each year to provide for increases in demand, to replace current production, and to provide for a decline in reservoir pressure.

Aside from depletion resulting from output, an oil reservoir, because of declining pressure with production, tends to yield less and less oil each year until finally exhausted. In other words, just to maintain current output would require us to run faster and faster to stay in the same place. For example, just to maintain an output of 3.1 B would require discovery of 3.2 B initially, but more than 4 B 10 years later, assuming an average decline curve.

If, on the other hand, we hoped to reach an output of 4 B annually by 1985 we would have to add an average 4.1 B per year to reserves over the next 9 years. In the past 30 years, reserves have only increased more than 3 B once, and that was the year Prudhoe Bay was added. Such a discovery rate is not sufficient to replace production, left alone balance the decline in reservoir pressure. To achieve adequate discovery rates requires the exploration of frontier areas where the probability of a major find is greater. It also requires a good deal of luck.

Potential production.—Estimates of future output made by various organizations between 1975 and 1977 indicate somewhat more optimism than indicated above. The estimates ranged between 4 and 5.9 B in 1985, and between 4.2 and 5 B in 1990. A recent CRS survey of the petroleum industry indicated an expected output of 4 B in 1985 and 4.2 in 1990. The key assumptions behind these figures were decontrol of oil and gas prices plus leasing of 1.5 to 2 million acres per year on the OCS.

The most recent Energy Information Administration (EIA) estimates indicated midrange output of 3.9 B in 1985 and 3.8 in 1990. The increased output in the latter years is dependent on success in Alaska and the OCS. By 1990 the EIA expects one third of domestic petroleum output to come from those areas, compared with 19 percent in 1977.

From the foregoing, it is apparent that U.S. petroleum output is expected to rise over the next 10 to 12 years, and may well reach a second peak sometime in the late 1980's or early 1990's. The increased output, however, would still not be sufficient to meet total U.S. demand.

It would thus appear that while the United States is not anywhere near out of oil, we will not be able to produce enough domestically to meet the bulk of our needs without turning to other sources such as oil shale, coal, et cetera. There is considerable controversy over this latter course, particularly in relation to the social costs.

ALTERNATIVE PATHS TO THE LAND OF PLENTY

As noted above, the use of what can be called high technology to solve our domestic energy constraint is considered by some to be too costly in a social sense. Those who hold this view have advanced an alternative path to the land of energy plenty.

The Lovins thesis

The most eloquent exposition on this latter position is by Lovins.[20]

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[20] Lovins, Amory B., "Energy Strategy: The Road Not Taken?" Foreign Affairs, October 1976, vol. 55, pp. 65–96.

His analysis is straight out of resource theory. It assumes resource scarcity and then asks what substitutes are available at what cost. The Lovins thesis starts with the assumption that substitutes will be required for oil and gas in the future. He then outlines two paths—the hard and the soft. The hard path is essentially an extrapolation of the recent past with heavy reliance on centralized, high technologies such as nuclear, coal gasification, et cetera, and substantial use of electricity. The soft path, on the other hand, involves conservation, the rapid development of renewable energy, and the use of special transitional fossil fuel technologies.

It is his contention that the two parths are mutually exclusive because the commitment of societal resources required for the hard path is such that nothing would be left for the soft. This mutual exclusivity occurs because the capital intensity of the hard path is so high that three-fourths of our cumulative net private domestic investment over a decade would have to be plowed into the energy industries compared with 25 percent at present. The heavy capital burden would increase over time resulting in the need to feed back into the energy system the multiplier dividend just to keep it going. That is, a dollar of investment not only creates more output where invested, but generates investment and output in other parts of the economy. This multiplier effect would, according to Lovins, have to be channeled back into the hard path thus leaving nothing for the soft.

It is his view that the hard path is not acceptable because it means producing more and more energy just to drive the energy industries, an enormous diversion of capital and other resources to energy production, high environmental and technologic risks, plus a major social commitment to highly centralized management.[21] It is Lovins' contention that the heavy demand placed on our economic resources will require the institution of resource allocation. He regards the hard path as the road to a world of subsidies, bailouts, oligopoly, considerable Government regulation, environmental destruction, loss of individual freedom, and a society less suited to the needs of man.

The soft path, on the other hand, is viewed by Lovins as the road to greater market competition, less regulation, lower and more stable operating and initial costs, and a generally more humane world. He notes that soft energy is renewable, diverse, flexible, low technology, and matched in scale, distribution, and quality to the end use. He specifically excludes from the soft category the various solar, ocean-current, and such technologies under investigation by the former ERDA and opts for less sophisticated solar-wind technologies. The ERDA work is considered to be high technology and capital intensive.

The Lovins analysis is essentially an application of the Zimmerman thesis discussed earlier. That is, the move to the soft path occurs as civilization requires it. Nature thus provides the energy, man the technology, and civilization the need.

Lovins rightly indicates that we now use large quantities of high-grade energy (electricity) for low-grade uses (space and water heat). The soft path would match the quality of the input energy to the use. It would also eventually eliminate the electric infrastructure (distribution, transmission, etc.), line losses associated with the transportation of electricity, and the generating reserve requirements of the electrical system since such components would no longer be needed. The soft path would use communal solar heated storage systems feeding into existing building heating systems as well as other dispersed technologies.

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[21] For a discussion of the impact of conversion losses see Kaufman, Alvin; Warren Farb and Barbara Daly, "U.S. Energy Demand Forecast, 1976–90", chapter in Committee Print 95–33 (footnote 12) pp. 108–129; and "Energy and the Economy" by the same authors, CRS for the Subcommittee on Energy and Power, Committee on Interstate and Foreign Commerce, U.S. House of Representatives, Committee Print 95-51, April 1978, 30 pp.

He recognizes, however, that there will be a need for transitional technology using fossil fuels with emphasis on coal. Lovins specfies cogeneration, district heating, end use efficiency, bioalcohol, and sophisticated but relatively benign coal technologies such as fluidized bed combustion for the interim period. He believes this would result in only a modest expansion of the coal mining industry estimated at double the present output at the height of the transitional phase. Lovins would also more or less convert existing electrical utilities into financial organizations. They would borrow money on the market, loan it to homeowners for soft path conversion expenses, and collect it back on a monthly basis, presumably earning a profit in the process.

A perspective on hard versus soft paths.—Needless to say, the Lovins proposal has stirred a good bit of controversy complete with salvos and countersalvos.[22] Much of the argument has centered on his implied, no-growth philosophy, the utopian nature of his proposal, the radical restructuring of our social, political, economic, and technological systems called for by the soft path, and the data used to justify the proposal. The latter item is of minor importance since the numbers provided on both sides of the argument are engineering estimates or forecasts colored by value judgments. For every position taken, there is a set of numbers to justify it.

In this regard, it should be noted that the Lovins thesis of mutual exclusion between the two paths is also a value judgment. That is a model, any model, is essentially an expression of the model builder's belief as to how something works. As such the answers derived are only an approximation of the future as the builder sees it. In any case, a forecast over a 50-year period or better, while it may be a useful analytical tool, cannot be definitive.

An alternative set of projections are provided by the Energy Information Administration.[23] That agency has estimated cumulative capital requirements for energy capacity over the 1978–85 period in a range of $336 billion to $385 billion (1978 dollars). This investment level would range between 19.6 and 21.2 percent of total nonresidential fixed business investment. In the 1960–77 period, energy investment ranged between 16 and 25.1 percent. The EIA estimates do not go beyond 1985 and the Lovins estimate of a capital "crunch" is presumably postulated for a later date.

The Lovins thesis, however, runs counter to our resource scarcity theory discussed earlier. If his investment estimates prove to be correct, the heavy fixed cost of energy capacity would be reflected in the sales price. As a consequence, demand would be lower, the conservation ethic would run rampant, and investment in new energy sources would slow down. The economy would probably operate at a more sluggish rate than might otherwise be the case, with unemployment somewhat above current levels.

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[22] Yulish, C.C., editor "Soft vs. Hard Energy Paths: 10 Critical Essays on Amory Lovins's Energy Strategy: The Road Not Taken?" Charles Yulish Associates, Inc., New York, 1977 and Lovins, A. B. "Soft Energy Paths: Toward a Durable Peace," Ballinger Publishing Co., Cambridge, 231 pp., 1977.

[23] See item listed in footnote 18B, pp. 53–57.

On the other hand, if the Government elected to subsidize energy consumers through the tax system, direct subsidies, or by permitting "rolled in" pricing, the price of energy would be below its real cost, consumers would be getting the wrong price signal and demand would rise faster than it should, encouraging even more investment. Under such a circumstance, however, it is likely that the economy would "boom" for a time. Economies are not perpetual motion machines, nor has Government intervention reached such a high state as to be without its problems. As a consequence, somewhere along the line would come the "bust". With it would come lower demand for energy, reduced investment, and a search for new policies.

In any case, the thesis that 75 percent of cumulative net private domestic investment would be soaked up by the energy industries implies that virtually the only industrial expansion undertaken in the United States would be in the energy industry. The Lovins thesis then must assume that most of the energy produced would be consumed as conversion losses by the energy producers since there would be few other consumers for the incremental energy. With such a lack of demand it would be extremely difficult for the energy industries to obtain the required capital. As a result expansion would falter.

While such a scenario is possible, it does raise the question of why a nation would want to produce energy for the sake of energy. As Lovins has noted, the consumer buys heat, light, etc. As a consequence, at some point, the staggering tax burden imposed by the energy subsidies would become apparent, a corrective action taken, or the economy would collapse. It is highly unlikely that the economy could perk along draining funds from the nonenergy sector to pay for energy to be consumed by the energy producer, at the rate assumed in the Lovins model. No amount of Government intervention could keep the machine greased and operating.

In his soft path alternative Lovins envisions the demise of the centralized utility system. This is highly unlikely. If for no other reason there would continue to be a need for backup heating systems to assure comfort when energy storage was inadequate—say, periods of prolonged cloudy weather, extreme cold, etc. Not only would such a system be necessary, but the backup electricity may be rather expensive since it would almost all be supplied on-peak. Baseload generation under the soft path would be relatively minor, and someone would have to pay for the plant and equipment standing idle waiting for the peak. Further, system reliability would have to be almost perfect because when people turned to the system they would be in dire need. Such a low margin for error could mean greater generating and transmission reserves and higher costs.

There is also a failure to appreciate the time required to introduce new technology such as fluidized bed combustion. It will probably be quite a few more years before that technology is ready for full-scale commercial use, and other relatively benign technologies will not be ready for even longer time periods.

In any case, the Lovins thesis does tend to gloss over the magnitude of the institutional barriers facing the soft path, and fails to appreciate the nature of investors in general and, arguably, Americans in particular. In the latter case, someone has noted that had Noah been an American, we would have seen the greatest waterworks ever, rather than the ark. Aside from this propensity to do things big, it is highly likely that there would be a great reluctance to invest in the interim energy economy leading down the soft path because of uncertainty as to how long the "bridge" period would last and the consequent ability of the investor to recoup his money with a suitable rate of return. Further, there would be considerable uncertainty as to the validity of the soft path economic projections. This would result in additional reluctance on the part of investors.

The interim economy would likely be an extremely expensive period of time. In addition, people tend to stick with things they know. As a result, it is highly likely that punitive prices, high cost incentives, rules and regulations would be needed to force the movement toward the soft path at the pace required to meet the Lovins goal. Simple incentives and education may not be enough. It is, therefore, entirely possible that the soft path would result in a more highly controlled economy and political regime than the hard path, at least in the early stages. A fair case can be made in speculation that once such controls were in place, they would not be easily removed.

The major contribution of the soft thesis is in pointing out the social-political aspects of the energy problem and in moving the energy argument away from the question of "how do we get someplace?" to "where do we want to go?". In this regard he has rendered a substantial public service; the size of the service may be judged by the speed with which rejoinders have been patched together, and the violence of the attacks, both indicating a sensitive nerve has been touched.

Essentially, Lovins is saying that attempting to deal with potential resource scarcity in the usual manner will impose substantial costs on society with little benefit. What he is saying may be correct, but the difficulty is that his solution may impose the very costs he seeks to avoid. In any case, the Lovins perception of the problem and its resolution represents a value judgment which may not be shared by the bulk of the population. It is unlikely that any solution will emerge until those individual perceptions and value judgments have coalesced into a consensus.

Finally, we already have in place a spate of laws nudging the economy toward greater conservation, and have a series of incentives toward such actions in the mill. At the same time, we are embarking on the various hard, soft, and intermediate technologies. In any case, both the hard and soft paths carry with them great uncertainty in terms of economic, political, and social impacts. When faced with such uncertainty prudence suggests a middle path using a mix of hard and soft until desirable directions become clearer. At a range of 50 years, a crystal ball is too cloudy to bet all of our national chips on a single path.

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